Human Factor Studies in Evaluation of Automated Highway System Attributes

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The goal of the Automated Highway System (AHS) is to blend engineering ingenuity and technology to produce a new level of transportation services. Human factors are difficult to integrate with AHS design because they represent a variety of training, experience, skills, and goals. Human factor considerations are essential for AHS design because humans will be involved in automated driving. For instance, drivers may be expected to instruct their vehicles to exit locations, input parameters such as speed and desired headway, or take control in some emergency situations. The tasks that human drivers will be expected to execute have not yet been fully defined. One human factor dilemma that AHS engineers might face is that if human drivers are not allowed to intervene in the vehicle control process during malfunction and emergency situations, they may be trapped in a system with high failure rates. This could result in public distrust and a lack of public will to deploy an AHS. However, if drivers are allowed to take control of their vehicles at will, some may intervene at inappropriate times, causing a potential system failure. A framework has been developed for evaluating human factor concerns for automated vehicle control. These concerns involve basic driving tasks: (*a*) detection, (*b*) recognition, (*c*) situation analysis, (*d*) decision making, and (*e*) control response. An analytical process to determine the responsibilities of the human driver, vehicle, and AHS infrastructure for these driving tasks is presented.

The Automated Highway System (AHS) blends engineering ingenuity and technology to produce a new level of transportation services. The National Automated Highway System Consortium (NAHSC) is in the process of evaluating system attributes for AHS development. These attributes include a mixture of automated and manual traffic on automated lanes; levels of automation; levels of responsibility and control at the driver, vehicle, and infrastructure; communication protocols; and human involvement in the driving task. One of the most important attributes that needs to be studied is the integration of automated systems with human operators.

Human drivers are difficult to integrate with AHS because of the variances and unpredictability of humans. Driver integration is important for two reasons. First, AHS is not, at this time, being developed to control all vehicles at all times; drivers will be expected to manually control their vehicles before entering and after exiting from AHS. Second, drivers may be involved in automated driving by inputting parameters such as speed and desired headway or taking control in some emergency situations. The tasks the driver will be expected to be involved in have not been fully defined; the focus here is to build an evaluation framework for these tasks.

ANALYSIS FRAMEWORK

This section presents a framework for appropriate human interaction in automated driving.

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Conventional Driving Framework

The first step in developing a framework for automation of human driving is to review the conventional driving process. This task has been thoroughly explained in the literature. A suggested framework for the conventional driving task developed by Michaels (*1*) is shown in Figure 1.

As shown in the Michaels model, driving is a complex process with numerous inputs. The first step in this process is sensory detection, the ability of drivers to see and hear their driving environment. Once the driver has detected these inputs, he or she must use the memory of past experiences and acquired knowledge to perceive the significance of these inputs, complete an analysis of the situation, use problem-solving skills to make a decision about the appropriate course of action to follow, and take action such as applying the brakes or steering. Finally, based on the roadway geometry and type and condition of both the pavement and vehicle, the vehicle will respond to the driver's action. Once this process is complete, the driver must sense the vehicle's reaction, beginning the process again. Thus, the driving process is a continuous process as the results of one iteration provide inputs for the following interactions.

AHS Control Process—Separate and Parallel Human and Vehicle Processes

This section develops a parallel control process framework to evaluate various AHS attributes. In automated driving, a range of inputs will feed into two (dual) parallel control processes, one being the human control process and the other being the automated control process (Figure 2). The outputs from these two processes will be fed into a driver-to-vehicle interface switch, which determines whether the human or machine has control of the vehicle and allows for human intervention in the control process.

Intervention modules may have several components: (*a*) emergency and vehicle malfunction modules may allow the driver to physically override the automated control process in crisis situations and (*b*) information query and vehicle instruction modules that allow the driver to input and extract information from the vehicle in noncrisis situations, leaving the vehicle's control process in place. The following analysis assumes that the driver has the ability to activate either of these modules at any time by physically taking control of the vehicle. This assumption is made for the sake of simplicity and has not been formally accepted by AHS developers. The assumption of driver intervention does, however, represent a worst-case scenario for design. If driver interaction is not considered, human factors can be largely ignored. Clearly driver integration into a system that allows driver interaction is more difficult to achieve.

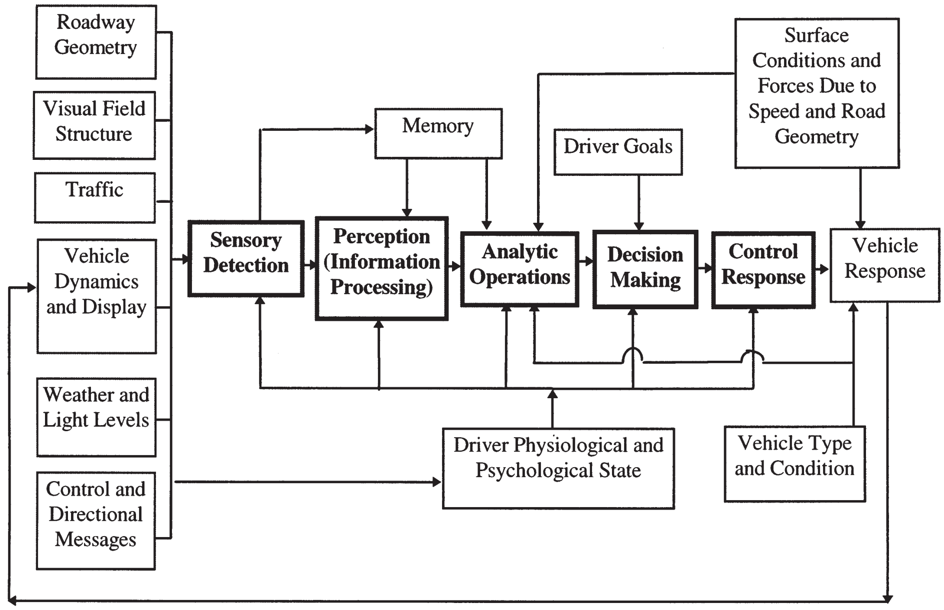

FIGURE 1 Conventional driving process (*1*).

Independent Vehicle

With the foundations of the conventional driving process and the dual parallel control processes in place, a framework can be applied to a situation where vehicles operate independently with no vehicle-to-vehicle communication or infrastructure support. These attributes could likely be found on a rural AHS and are similar to Bayouth's Free Radical Concept (*2*).

Figure 3 shows a framework for the vehicle control process and demonstrates why dual and independent systems are necessary. In Figure 3, the dual systems are not cross linked. For either of these processes to function, information must first be provided in the Sensory Detection or the Data Collection module. Therefore, even if vehicles are equipped with an advanced "heads up" display using data from its sensing capabilities, the driver will still need to sense the information on the display as a start to the guidance and control process. Drivers will remain limited by their perception-reaction process. Figure 3 also shows that the vehicle control process is similar to the human control process in that the vehicle will be required to

- Collect data through sensors and communications equipment,
- Interpret the raw data to produce meaningful information that can be used by on-board-computer software,
- Analyze the information with computer models,
- Choose an optimal action solution, and
- Act on the solution.

Some preliminary requirements for different types of automated systems can be drawn from this application. For instance, the vehicle's data collection and interpretation capabilities will have to be

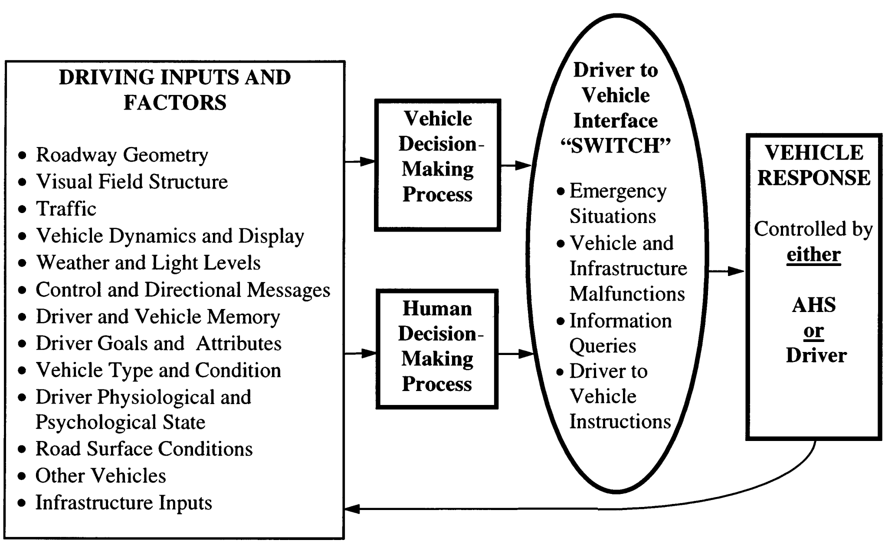

FIGURE 2 Parallel and separate human and vehicle control processes.

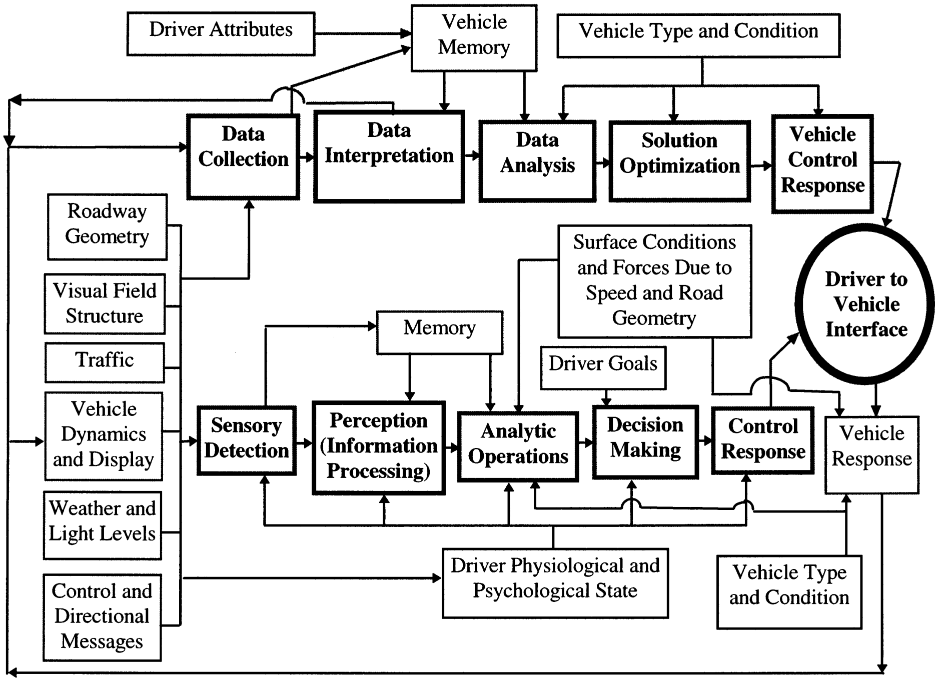

FIGURE 3 Human integration in the Bayouth Concept (*2*).

able to recognize traffic control devices such as street signs, signals, and road markings in all weather conditions in spite of temporary obstructions (i.e., partially obscured by snow) and react appropriately. In rural areas, this system may be required to tell the difference between a deer standing on the side of a highway and a cow in a fenced-in pasture. This control process is relatively simple in that it is not required to communicate with other vehicles or the infrastructure. However, it demands a high level of sophistication from the vehicle's systems.

Infrastructure Support with Traffic Management

The Infrastructure Support with Traffic Management example is similar to the Infrastructure-Supported and the Infrastructure-Assisted Concepts explored by the California PATH Program in early 1996 (*3*). The application of the human intervention framework to this example is shown in Figure 4.

The addition of vehicle-to-vehicle and vehicle-to-infrastructure communication in these new concepts complicate the control process but may add new capabilities. For example, once automation is mature and automated networks exist, this may allow for more efficient routing of vehicles through an AHS network. This system may also allow some limited infrastructure control for signs, speed limits, and separation policy.

HUMAN-VEHICLE INTERFACE

The driver-to-vehicle interface is the system by which the human driver can interact with the automated vehicle. Its operation was developed in Figure 2 and encompasses four main areas:

1. Emergency situations,
2. Vehicle and infrastructure malfunction,
3. Driver queries, and
4. Driver-to-Vehicle Instructions.

As previously discussed, this interface allows the driver to appropriately access the vehicle control process. Answering questions regarding how, who, when, and where to implement each of the four functions of this interface must now be addressed.

Emergency Situations—Vehicle and Infrastructure Malfunctions

The most complex area covered by the human-to-vehicle interface is cross-cutting procedures whereby the human driver is able to physically take control of his or her vehicle in emergency and malfunction situations. Cross cutting may degrade the efficiency of an AHS but may be desirable for the following reasons:

- It may increase user confidence in an AHS,
- Emergencies can be difficult to predefine and an attempt to do so would risk excluding unforeseen events,
- Malfunctions may cause the cross-cutting authorization process to fail, and
- Events requiring driver intervention may require short reaction times on the part of the driver, and an authorization process may take too much time for driver intervention to be effective.

No attempt is made here to define the circumstances for which driver intervention should be allowed. Here, the worst-case scenario for AHS developers is assumed, that is, driver intervention is allowed at all times. In final AHS design, driver intervention may only be allowed in limited situations or it may not be allowed at all. Research is needed to define the appropriate times and circumstances by which driver intervention will be allowed, and that analysis is left to future research.

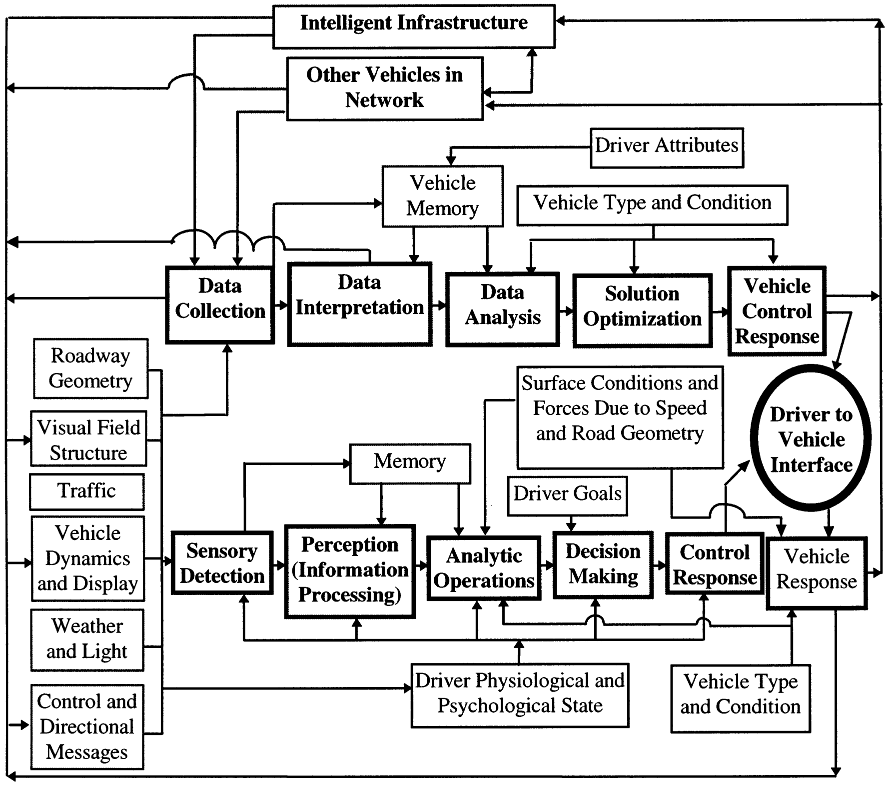

FIGURE 4 Human integration with infrastructure support and vehicle-to-vehicle communications.

In all cases of cross cutting, the method by which the driver will regain control of his or her vehicle must incorporate the driver's instinctive nature because cross cutting would occur in emergency and malfunction situations that are sudden and require an immediate response. Human reaction in these situations is in accordance with the driver's experience and training. The following is a list of some examples in which human cross cutting may occur. This list is not complete, but provides an idea of what might be reasonable scenarios.

- Child or animal runs out in road,
- Accident occurs in vehicle's path or vehicle is cut off by another vehicle,
- Brakes, steering, or power fails,
- Tire fails,
- Vehicle display fails, and
- Erratic vehicle behavior occurs.

One reason driver intervention might be important is that it may pose an interesting dilemma to AHS designers. It is reasonable to assume that, if allowed, some drivers will intervene in the driving process and their actions will have a negative effect on AHS systems operations. However, if human drivers are not allowed to intervene in the vehicle control process during malfunction and emergency situations, they may be trapped in a system with high failure rates. This situation could result in public distrust and a lack of public will to deploy the system.

It will be very difficult to develop AHS to the point of zero system failures, which suggests that drivers should have an option of taking control of their vehicles during emergencies. However, if one allows drivers to take control, and does not regulate when and how they take control, some drivers will take control at times that may not be appropriate. This suggests that an AHS system should be able to regulate when a driver is allowed to intervene in the automated process; however, it is very difficult to regulate when and how a driver can take control. A poorly structured interface procedure might preclude the driver from taking control in a safe manner because of human perception-reaction time and the possibility of system failure in switching vehicle control over to a driver. This issue has not been resolved and is a ripe area for future studies.

Driver Information Queries and Instructions

Driver information queries and instructions are instances of human-vehicle interfaces when the driver can interact with, but not take control of, the vehicle. For instance, the driver could determine the effect of altering his or her route to a final destination while en route. These interfaces should provide the driver with influence over the vehicle systems required for normal driving.

AHS Requirements

AHS will have several requirements based on the above cross-cutting analysis. If cross cutting is allowed, the AHS must have the capability to know when cross cutting has occurred and take appropriate corrective actions. One potential solution to this problem is to allow enough spacing between vehicles so that the following vehicles are able to safely stop if the lead vehicle applies its full braking capability. In this way, if the driver of the lead vehicle takes control of his or her vehicle by applying full braking capability, then the following vehicles will be able to come to a safe stop under automated control. The following distances, then, would not be a constant value, but would vary by local conditions and vehicle mix. For example, a sports car might be allowed to follow a tractor trailer combination at a much closer distance than a tractor trailer combination would be allowed to follow a sports car. This following-distance criterion then requires the following vehicle to know the lead vehicle's braking capability. For this to take place, all vehicles would be required to know their own maximum braking capability and communicate this with other vehicles. Maximum braking capabilities would vary by vehicle, depending on vehicle load and maintenance status as well as pavement condition. This requirement, however, may be difficult to implement in the field because of a potential variance of pavement conditions.

CONCLUSIONS

A framework for evaluating human involvement in automated driving has been presented. The discussion and figures present a step-by-step process that explains the roles of both the human and vehicle control systems. Flow charts depict the relationship between the driver, the vehicle, and the infrastructure. This framework can be used to evaluate various concepts for feasibility and effectiveness. The analysis assumes that automated vehicles will always act on their own, until the human driver assumes the driving task. The actual transfer of vehicle control from vehicle to driver, and vice versa, is an issue that needs further study because it must be designed to allow for an instinctive human reaction. Crosscutting poses an interesting dilemma for AHS designers: human drivers who are not allowed to intervene in the vehicle control process during malfunction and emergency situations may be trapped in a system with high failure rates, which might depress marketability of AHS; however, if drivers are allowed to take control of their vehicles at will, many will intervene at inappropriate times, causing congestion and a potential AHS failure.

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